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AUTHOR	Preston, Ron; Rachlin, Sid; DeBellis, Valerie; Robinson, Zachary; Sinicrope, Rose
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ABSTRACT

This paper describes the mathematics concentration program at East Carolina University (ECU) that is taken by preservice middle grades teachers intending to teach mathematics. Following a brief examination of the forces that impacted the formation of this mathematics concentration, this paper describes the program and highlights five courses from a development perspective. The five courses are: Algebraic Concepts and Relationships, Data Analysis and Probability, Pre-Calculus Concepts and Relationships, Discrete Mathematics, and Applied Mathematics via Modeling. (Author)

Improving the Preparation of Middle Grades Mathematics Teachers: The Case of East Carolina University

Ron Preston, Sid Rachlin, Valerie DeBellis, Zachary Robinson, and Rose Sinicrope

This paper describes the mathematics concentration program at East Carolina University (ECU) that is taken by preservice middle grades teachers intending to teach mathematics. Following a brief examination of the forces that impacted the formation of this mathematics concentration, we describe the program and highlight five courses from a development perspective. The five courses are Algebraic Concepts and Relationships, Data Analysis and Probability, Pre-Calculus Concepts and Relationships, Discrete Mathematics, and Applied Mathematics via Modeling.

Background

In the early and mid-1980's, some states began requiring teacher education programs to prepare undergraduates for certification specifically as middle grades mathematics teachers. Typically, these middle grades programs borrowed courses from existing elementary or secondary programs. The results were — and often still are — a hodgepodge that does not address the specific needs of middle grades teachers. The initial middle grades program at ECU was little different. Included in the *collection of courses* were the number course for elementary education majors, the business calculus course, an introductory statistics course, and college algebra.

In 1994, ECU initiated the NSF-funded MIDDLE MATH Project (DUE-9455152) with the goal of making the program meet the needs of future middle grades mathematics teachers. This undergraduate faculty enhancement effort involved sixty mathematicians and mathematics educators from across the country in an effort to define the content, instructional methods, and tools needed to develop effective programs. *A Call for Change* (Mathematical Association of America, 1991), recommends that if existing courses do not provide the content preservice middle grades teachers need then "special courses should be developed that provide the proper focus and breadth of experience for these teachers" (p. 17). This document recommends a core of content in number concepts and relationships, geometry and measurement, algebra and algebraic structures, probability and statistics, and concepts of calculus. These courses need to provide preservice teachers with the opportunity to gain knowledge and understanding considerably deeper than what they are required to teach. Courses must also stress mathematical concepts and procedures and the connections among them (National Council of Teachers of Mathematics [NCTM], 1991). Another approach for determining the necessary content is to examine grade 5–8 standards-inspired curricula and design courses that provide a foundation for this content. To this end, an author from each NSF-funded middle grades curriculum project was present at the MIDDLE MATH conference to suggest the mathematical experiences preservice teachers should have.

Pedagogy is another important issue in teacher development. Attention must be paid to the pedagogy of the college classroom, given the strong belief that teachers teach as they were taught (National Research Council, 1989). Preservice teachers must experience the active climate they will be expected to create in their classroom. Participants in the conference discussed pedagogy in

the context of the curriculum projects and based on interviews with middle grades teachers.

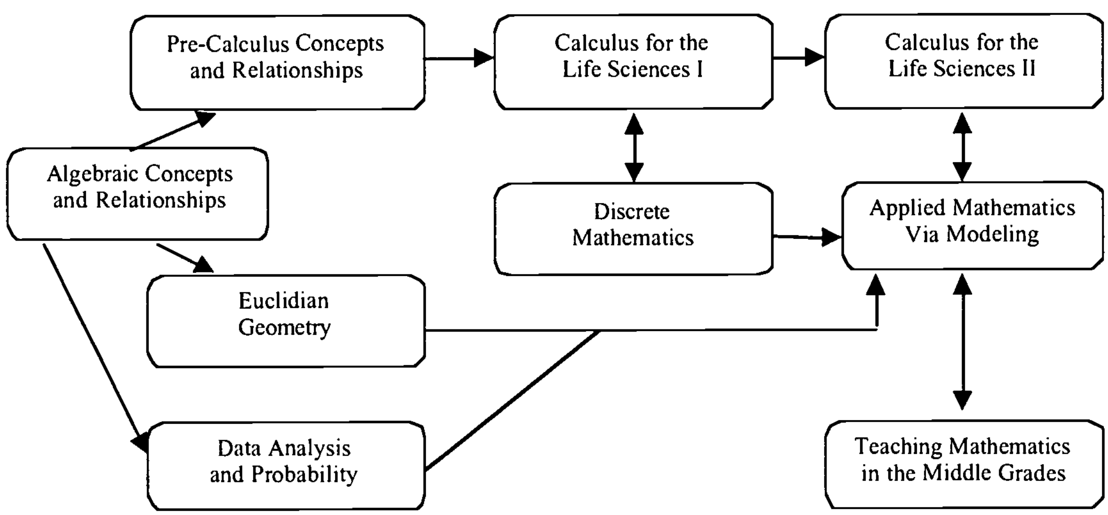
To assist universities in creating new courses and programs, the MIDDLE MATH conferences featured key-note addresses given by faculty from previously-funded Middle School Mathematics Teacher Preparation Programs. Participants also read materials such as the *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), and *On the Shoulders of Giants* (Steen, 1990), in addition to the already-mentioned documents.

Using the MIDDLE MATH Project as the impetus and knowledge base, each university proposed to develop new courses or programs or to modify existing courses or programs. ECU redesigned their program, using input from reform documents, new curriculum projects, competencies from the state of North Carolina, and the interests, expertise, and philosophy (e.g., that the program have a strong problem-solving focus) of their faculty. The new program is described below, a program that includes only the Euclidian geometry class from the previous program.

The Program

The mathematics concentration at ECU is primarily designed to prepare teachers of middle grades mathematics, but it does serve other populations. The most significant of these populations is the group of elementary education majors who choose to concentrate in mathematics. The concentration serves some preservice business-vocational and exercise science majors. Each of these three majors requires a concentration, with mathematics being one of several choices.

Eight mathematics courses make up ECU's mathematics cóncentration. Preservice middle grades mathematics teachers also take a mathematics methods course as shown in the figure below.



In this paper, we describe five of the concentration courses in some detail. Following is the catalogue description for each of the other three mathematics courses and the methods course.

- Euclidian Geometry. Study of Euclidian geometry using deductive and inductive mathematical

reasoning. Formal proofs are required.

- Calculus for the Life Sciences I. Introductory differential calculus with applications for students in the biological sciences. Introduction to and differentiation of the exponential, logarithmic, and trigonometric functions; with applications to exponential and periodic phenomena, related rates, regions of increase, and extrema.
- Calculus for the Life Sciences II. Introductory integral calculus with applications for students in the biological sciences. Introduction to and applications of definite integrals. Probability density functions. Functions of several variables, partial derivatives, simple differential equation and difference equation models, and the arithmetic of matrices and vectors.
- Teaching Mathematics in the Middle Grades. Study of techniques and methods of teaching mathematics in grades 6-9. (This three-credit hour course meets four hours per week and includes 10-12 hours of field experience. It is taught in the Department of Mathematics.)

Algebraic Concepts and Relationships (Sid Rachlin)

The first course in the ECU's new concentration for prospective middle grades mathematics teachers, Algebraic Concepts and Relationships, is designed to replace College Algebra as the introductory level course taken by *all* prospective middle grades teachers. The purpose of the course is to have students take a reflective look at algebraic systems to deepen their understanding of algebraic properties and interconnections. Rather than use a textbook, students work on a series of twenty problem sets. New topics are introduced through the class discussion of problems. The course focuses on the processes students use to solve problems. Assignments are designed to promote the development of conceptual understanding over time. Each topic is developed over the course of several problem sets. The problem sets include problems from middle grades student materials, real world applications, skills development, analysis of student errors, reading assignments which are often tied to research on student learning or research on teaching, and a writing or journal assignment.

In Algebraic Concepts and Relationships, the topics are arranged to provide prospective teachers with a thorough knowledge of the number systems and algebra they are going to teach, as well as some idea of how it can be used as a foundation for later development. The course is organized to present a generalized view of algebraic operations, rather than a set of unique operations for each number system. The operations of equivalence, addition/subtraction, multiplication/division, and power/root drive the curriculum—rather than a separate study of whole numbers, integers, rational numbers, real numbers and polynomials. Students see the same operation in a variety of situations and are encouraged to make connections between the operations using real numbers and the operations in algebra. For example,

a. Find two fractions with unequal denominators, in lowest terms, whose difference is 2/13.
b. Find two binomials whose difference is a trinomial.
c. Find two real numbers of the form $a + b\sqrt{5}$, where a and b are nonzero real numbers, whose difference is -10.

The last third of the syllabus includes a foundation for the concept of *function*. The processes examined in this section include interpreting functions, graphing functions and then interpreting the graphs and solving equations.

The problem sets emphasize the NCTM (1989) curriculum standards of problem solving, reasoning, connections, and communication and the following four "big ideas"—(1) reflection on acquired knowledge, (2) ties to the middle grades classroom, (3) tools for learning, and (4) research on mathematics teaching and learning.

Preservice teachers in Algebraic Concepts and Relationships should recognize direct connections between the mathematics they are learning and the mathematics they will be teaching. To tie the course to the middle grades classroom, problem sets include tasks taken from the curriculum projects funded by the NSF. Some of these problems are used as models for concept development. Others are used as models for the reinforcement of skills. In either case, the problems are referenced so students know from where they are drawn. Students benefit both by doing the problems and then discussing why and how they might use them in their future teaching.

Algebraic Concepts and Relationships also tries to make learning a more hands-on experience than in the traditional college classroom. Graphing calculators and spread sheet programs are used to talk about functions and equations. Pebbles, algebra tiles and lab gear, base five blocks, and fraction bars are used to help students explore the operations of number and algebra.

The readings assigned in a problem set are often selected from publications that translate research for use in the classroom. Occasionally, a class stops in the middle of a lesson and reflects on the pedagogy that was just used in the discussion or presentation of material. Teachers use different techniques to get their point across. Often, students do not realize these are techniques that they themselves can learn. To have directly experienced an example of a teaching technique in a content course is more valuable than simply reading or watching the same example.

Another type of problem included in the problem sets is one in which a middle grades student's solution for a math problem is provided. Preservice teachers are asked to identify any errors and determine how they would correct the student's work. Often these fictitious problems are presented as writing assignment, so the students express their observations and corrections in writing. It is not enough for a student in Algebraic Concepts and Relationships to be able to solve a problem—they need to communicate—to listen and seek to understand the solutions of others, to explain their solutions in a way that others can understand, and to search for links between their solutions and the alternate approaches.

Pre-Calculus Concepts and Relationships (Zachary Robinson)

Four semesters ago, a course development team was assembled. It consisted of a high school teacher, a college instructor with a math education background, and two research mathematicians. It was charged with developing a course for prospective middle grades math teachers that would give them (1) a foundation for the two-semester Calculus for the Life Sciences sequence, a required part of their chosen concentration, and (2) a perspective on the middle grades math curriculum. At this stage, the team has produced course notes and problem sets designed around a streamlined syllabus with a unifying mathematical theme.

At the initial stage of development, the team was guided by a critical appraisal of the standard pre-calculus course. Often, such a course has a syllabus designed around a rather wide variety of techniques, where the instructor produces a formula and students use it to solve canonical problems. By the time the students begin the next semester's calculus course, a significant segment of them neither retain the skills nor have had a chance to develop a feel for the structural concepts that are later exploited in the development of calculus. Another segment of students simply seem to lack the mathematical background to succeed in the typical pre-calculus course. The team's task at the first stage, then, was to develop a streamlined syllabus with a unifying mathematical theme.

The unifying theme of the Pre-Calculus Concepts and Relationships syllabus is the close mathematical relation between algebraic techniques and the geometry of graphs of algebraic expressions. This is developed partly through pairing topics such as: similar triangles and linear slope, qualitative properties of polynomial graphs and factoring, asymptotes of rational functions and polynomial long division, rigid motions and transformation of equations, and rigid motions and exponential invariants. The topic of rates of growth — linear and non-linear (among the latter, especially exponential) — appears throughout the course, drawing out the main theme in a different way. Certain points in the course are taken as opportunities to present "glimpses of calculus," with activities such as (1) drawing tangents to graphs with a ruler and estimating their slopes and (2) trying to find local extrema, which is easy for parabolas, but not so for graphs of rational functions (especially without calculus).

The course's streamlined syllabus leaves ample time for in-class activities. Ungraded flash quizzes bolster the most basic skills students will need to tackle calculus. Small group cooperative activities support exploration. For instance, students use examples to develop first an algorithm and then a formula for completing the square. They also work selected problems from the problem sets, which they are either expected to write up carefully later or to present to the class. Another sort of class-time activity is "relay problem-solving," where the instructor breaks a difficult problem down into smaller tasks, then calls on students in turn to explain the solution of the task at hand.

The next stage of development will entail a complete rewriting of the course materials. Although the syllabus and choice of topics should be preserved, it would be desirable to structure the course around a constructive learning approach and to create materials that will give students a perspective on the middle grades math curriculum. The development team began its work with a semester of video observation (both classroom and individual student interview sessions) of the Algebraic Concepts and Relationships course described elsewhere in this article. The teaching of that course is based on the premises that (1) problem sets introduce the ideas, (2) classroom activities and the instructor guide students in systematizing the ideas, and (3) consolidation of math skills follows basic acquisition of concepts. Those who have taught students who have taken that course have observed greater levels of retention, self-reliance and mathematical maturity.

Data Analysis and Probability (Rose Sinicrope)

Data Analysis and Probability is a non-calculus based introduction to the basic principles of statistics. Probability links data collection, summary, and display with statistical inference. Topics include average, standard deviation, stem-and-leaf plots, box plots, the histogram, the normal curve, correlation, regression, chance, the law of averages, the expected value and standard error, normal approximation for probability histograms, sampling, chance error, and confidence intervals. The course fulfills the final mathematics requirement of students with a middle grades major (i.e., those students not concentrating in mathematics).

The course was developed over a period of two years by a team of two mathematics educators, Ron Preston and Rose Sinicrope, and a statistician, Mike Hoekstra. The course can be described as the integration of David Freedman, Robert Pisani, and Roger Purves' (1998) *Statistics* text, the TI-83 calculator, and middle grades curriculum activities.

Mike Hoekstra selected the text. It is unusual in its careful, student-centered development of concepts. There is an emphasis on reasoning. For example, students may be given several different histograms and asked to decide which histogram has a mean greater than the median. A question that raises a lot of discussion is a report of the average age of death from data collected in a cemetery and the preponderance of years that end in zero or five. Reversibility questions are frequently asked. For example students may be given the average and standard deviation of a small data set and asked to determine the data. Emphasis is placed on understanding statistical concepts. For example, an exercise describes a group of ten people with an average height of 66 inches joined by a person who is 77 inches tall, and students are asked to determine the average height of the eleven people in the room. Class discussion will reveal different approaches to this question, but will emphasize the leveling concept of average. Later in the course there is a heavy emphasis on average as the balance point of a histogram. Computational formulas are not used in the course. Statistical concepts are described in words rather than mathematical symbolism. For example, the standard deviation "says how far numbers on a list are from their average." The standard deviation is "the square root of the mean of the square deviations from the average." Concepts are introduced through discussion of historically significant studies and are developed through exercises using computationally simple data sets and interpretations of graphs. For example, correlation is introduced through Karl Pearson's study of the relationship of heights of fathers and their adult sons, and the binomial formula for probability is developed as an account of Pascal and Fermat's analysis of questions raised by seventeenth century French gamblers.

The TI-83 graphing calculator is used throughout the course as a tool and as a method of exploration. Students use the statistics functions of the calculator to compute one and two variable statistics; to graph histograms, box plots, scatter plots, and residual plots; to generate random numbers; and to determine areas under the normal curve. For a small data set, the list functions are used to compute the standard deviation or the correlation coefficient using their definitions and by manipulating the lists. Students are challenged to make sense of the symbols and icons of the calculator.

Activities from middle grades curricula are used to explore mean and the relationship between

mean, median, and mode. Rainbow cubes and unifix cubes are used in these activities. Middle grades materials are also used for stem-and-leaf plots, box plots, histograms, and the interpretive value of standard deviation. Class activities and assignments include popular problems from middle grades instruction such as the chocolate chip cookie problem, the cereal box prize collection problem, the manatee and motorboats problem, and the m&m candies problems. Students also complete at least one project during the course in which they must research the state curriculum and school instruction.

The course continues to evolve. The greatest change is in the integration of school curricula. It is becoming a more integral part of the course. There has been some experimentation with student use of computer technology. In addition to the development team, two other mathematics educators have taught the course. Unfortunately, we do not have a formal structure for assessment and further development. However, we do some informal sharing of methods and materials, and we are able to follow the students through their senior year and some of their field experiences. Students are comfortable teaching statistics and probability concepts and enjoy using a statistical approach to integrate mathematical topics and other school instruction.

Discrete Mathematics (Valerie DeBellis)

Although the term "discrete mathematics" may seem unfamiliar to students, many of its themes are already part of the middle grades curriculum. Whenever objects are counted, ordered, or listed; whenever instructions are precisely followed; whenever games are played and analyzed; teachers are introducing themes of discrete mathematics. This course is based on five major themes of discrete mathematics which are appropriate for K-12 classrooms – systematic listing, counting, and reasoning; using discrete mathematical models (e.g., graphs and matrices); applying iterative patterns and processes; organizing and processing information; and using algorithms to find the best solution to real-world problems. Additional topics, such as set theory and logic are included in this discrete mathematics course to fulfill objectives of the mathematics concentration.

The following topics are covered in our semester-long course: *Combinatorics* – permutations, combinations, binomial coefficients, and counting problems; *Graph Theory* – coloring & conflict resolution, Euler circuits & paths, Hamilton circuits & the traveling salesman problem, spanning trees, shortest routes, directed graphs, and critical paths; *Matrices* – matrix operations, systems of linear equations, inverses, determinants; *Iteration, Recursion & Fractals* – principle of recursive definition, Sierpinski triangle, Koch snowflake, creating fractals and observing the perimeter and area; *Linear Programming* – graphing and Simplex methods; *Social Choice* – voting methods (plurality, majority, run-off, sequential run-off, Borda count, and Condorcet); fair division (continuous cases for $n = 2$ & 3, discrete cases for method of markers, and estate division); apportionment (Hamilton's, Jefferson's, Adam's, and Webster's Methods); *Set Theory* – notation, operations on sets, ordered n-tuples, Cartesian products, and Venn Diagrams; *Logic* – truth tables, logically equivalent statements, converse, inverse, contrapositive, counterexample, basic arguments (testing validity) and switching networks; and *Mathematical Induction*.

Instructor goals for the course are 1) to create an interactive mathematical environment in the

college classroom, 2) to develop mathematical independence outside the college classroom, and 3) to establish connections between discrete math topics and the traditional middle school curriculum. The first goal is accomplished through fostering a safe environment for all learners, by modeling a variety of pedagogical styles and by developing problem-solving abilities through group work and writing. If you pass by this class at ECU, you would see a variety of learning environments: traditional lecture mode of instruction, students actively working together on problem sets, becoming actors in a mathematical play, cutting pieces of paper to create a giant fractal, or arguing how to fairly divide a bag of hard candy.

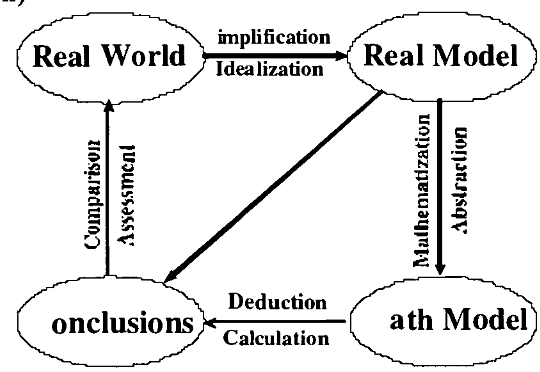
The second goal — developing mathematical independence outside the college classroom — is intended to help strengthen students' mathematical abilities by weaning them away from the mentality that "the teacher has all the answers". Students are forced to rely on their own problem-solving ability (or that of others in the class) instead of waiting for the instructor to provide solutions. All homework assignments must be accomplished in groups and often students will learn new mathematical concepts related to topics covered in class through the solving of these problems. Most homework problems are not discussed in class, yet students are held accountable for being able to solve and understand such problems. By allowing homework problems to remain unsolved for longer periods of time, students learn that they often need to "revisit" a problem several times and/or speak with several people before finding a solution. It is our intention for students to experience the learning of mathematics from peers outside the classroom; new mathematical content does not have to be transmitted from teacher to pupil inside a classroom. Although some students find this process painful, a wonderful byproduct has been that students often become more confident in their own problem-solving abilities; we require active participation in solving problems and mandate that students find solutions themselves.

The third goal — establishing connections between discrete math and traditional middle school curriculum topics — is intended to model ways of implementing discrete math topics in middle grades classrooms. This is accomplished through reviewing the middle grades competencies of the North Carolina Standard Course of Study and having students identify where the discrete math topics appear or how a topic can be integrated into a traditional math lesson (for example, the graphing method for linear programming fits nicely into a lesson on graphing lines). Homework assignments and test questions require students to design middle-grade-appropriate discrete math problems and we provide excellent middle grades resources, such as websites and ready-made classroom materials, so that by the end of the semester a pre-service teacher has begun to build a discrete math filing cabinet for use in his or her future classroom.

This course has gone through several changes, with the latest version developed over the past two years. During this time, it has been taught three times. Many activities used in the course were developed by a team of two mathematicians, Robert Hochberg and Joseph Rosenstein, and one mathematics educator, Valerie DeBellis, through the NSF-funded Leadership Program in Discrete Mathematics based at Rutgers University (see Rosenstein and DeBellis, 1997). Although DeBellis is constantly revising the course in terms of new activities, the most pressing

need is to incorporate technology into the classroom. To date, there has been no meaningful implementation of technology in the course.

Applied Mathematics via Modeling (Ron Preston)



Applied Mathematics via Modeling is a study of mathematical modeling and its applications to real-world situations. This study takes place on two fronts: (1) a study of success stories in modeling that demonstrates its *power* and *limitations* and (2) work on real-world and whimsical problems, using a modeling approach (see the model of mathematical modeling at right) to develop tentative "solutions." It is not the intent of this class to teach new mathematics — rather how to use the mathematics in the concentration. However, students often do learn mathematics they knew before only at a surface level.

The modeling course is the capstone for the mathematics concentration. The course goals are to:

- Investigate applications of mathematics through problems from number and algebra, geometry, data analysis and probability, pre-calculus, calculus, and discrete mathematics.
- Learn to examine the usefulness and limitations of classic mathematical models. (In this course models are abstract mathematical representations of real situations.)
- Learn to develop mathematical models through a modeling process. This work should lead to an understanding of the importance of assumptions in the process and should demonstrate the variety of strategies and models that can be used to "solve" a problem.
- Learn to analyze models for their strengths and weaknesses. This involves testing models against the problem context and acknowledging the importance of model revision.

Applied Mathematics via Modeling is in large measure a project-oriented class. Projects are done outside of class in teams of two to four students. Teams are typically given two plus weeks to complete the project and hand in the accompanying report. The sample below is a "real-world" task (i.e., I was asked to solve the problem) entitled "Are You in the Ballpark?".

> An associate athletic director wants to sell advertising on the outfield fence of the university baseball field. The advertisements will be painted on signs the height of the fence and 10' long. He wants to know how many signs he can sell to various merchants and industries. From home plate, it is 330' to the right- and left-field fence and it is 390' to straight-away center-field.

A quick glance at the task gives a window into the open-ended nature of the projects. Depending upon the assumptions made, the task can be perceived in very different ways. This problem also has a variety of solution options from different mathematical domains as shown below:

- Look for lower and upper bounds by assuming the outfield fence is a circular arc centered at

home plate with a 330' radius (lower) and then 390' radius (upper).

- Assume the outfield fence consists of two linear pieces meeting at 390' from home plate and make successive uses of the Pythagorean Theorem.
- Assume a polynomial (e.g., quadratic) fits the outfield fence. Find a function that fits the data and calculate the arc length using a formula from calculus. This can be done with only the three points (distances) given or with assumed power alleys.
- Assume the outfield fence is a circular arc. Use trigonometric relations to locate the center of this circle along line from home plate to straight-away centerfield.
- Make a scale drawing (construction) and use measurement. Some students use technology to construct their ball park and some use paper, pencil, compass, and straight-edge.

As students work on projects outside of class, they investigate important models during class sessions. Following are a few of the models and a brief description of each.

- Introduction to mathematical modeling. Involves a series of mini-projects that when explored exposes the need for a modeling process.
- Mendelian Genetics. Study of the probabilistic model Mendel used to describe genetics.
- Population models. Investigation of data-driven models useful for describing growth or decay of varied populations. Includes linear, polynomial, exponential, and logistic models.
- Voronoi Diagrams. Exploration of a geometric model for solving problems such as "where should district lines be drawn so that every student attends the school nearest her/his house?"
- Weighted voting models. Examination of two discrete models (Banzhaf Power Index and Shapley-Shubik Index) for describing decision-making power in weighted voting situations.

Applied Mathematics via Modeling has been taught five times over the past three years. I see it as always open to revision in terms of new projects and different models, but the most pressing need currently is to further integrate technological tools for assisting the mathematical understanding of real-world contexts. These tools include computer applets for simulation, sensory probes for data collection, and software packages for analysis of, say, linear programming.

Next Steps

Preparation of middle grades mathematics teachers at ECU will continue to undergo examination, revision, and improvement in the coming years. In December 1999, we had a subset of our first group of mathematics concentration graduates back on campus to provide feedback about the program. The vast majority of their comments were highly favorable. The teachers noted that the program was not what they expected. In particular, it was student-centered instead of being lecture-oriented, it focused on solving problems in multiple ways, it balanced content and pedagogy, and it gave them confidence in their ability to teach mathematics. However, they also gave us reason to think about certain aspects of the program. Following are some of the questions that will drive our assessment of the program and its courses. Should we continue using the two semester calculus sequence, use an existing one semester course, or develop a "concepts of calculus" course especially for our students? What should the existing geometry (and measurement) class be? How can we better integrate technology in the existing classes? In addition, new documents will provide further points for reflection. For example, what impact

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	E-Mail Address: rachlins@mail.ecu.edu Date: 8/23/01

should the *Principles and Standards for School Mathematics* (NCTM, 2000) have on our program? Certainly our students, and in turn their future students, deserve our careful consideration to these and other issues as we continue to improve the mathematics education of preservice middle grades teachers.

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